Unstructured Model-Based Wave-Current Coupling: Application to the Grand Haven area of Lake Michigan

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ABSTRACT

It is widely known that currents are influenced by surface waves primarily by way of surface wind stress, radiation stress, and bottom stress. The complex physical processes also challenge scientists and require additional work. This poster describes a study that investigated the effects of waves on nearshore circulation in Lake Michigan near Grand Haven, MI. The Finite Volume Coastal Ocean Model (FVCOM), a three-dimensional unstructured grid estuarine and coastal ocean circulation hydrodynamic model, was coupled with the FVCOM-SWAVE. Particularly it was used to model the three-dimensional effect of waves on nearshore circulation and velocity fluctuations at the mouth of the Grand River and the adjacent beach area. The individual and coupled effects of the river discharge, waves, ambient flow, and atmospheric winds on the nearshore circulation are discussed and summarized here. River discharge and ambient flow have little influence on the nearshore circulation, but they interplay with the wave forcing at the coast. It was found that among the processes that waves present to the system, radiation stress and current-wave interaction are more important than wave-induced bottom stress. Also we are aware the bottom topography is the key for wave-induced circulation. As a next step, high-resolution bathymetry was provided to calibrate the numerical model and compare it to ADCP data.

INTRODUCTION

Wave and current interactions are an important aspect of hydrodynamics, especially at the beach and nearshore scales. The wave-current system also has a direct relationship to societal issues such as beach health, environmental protection, and recreation. The currents resulting from this wave-induced circulation many times control the nearshore transport. As a testbed, Grand Haven Beach was selected for this modeling study both for the Great Lakes and the Coastal Ocean. The Grand River, with a drainage area that accounts for 13% of the entire Lake Michigan watershed, is the largest tributary entering Lake Michigan. Grand Haven Beach is located at the mouth of the Lower Grand River on the eastern shoreline of Lake Michigan at Grand Haven in Ottawa County, Michigan. There are also several highly utilized and often contaminated beaches in this area.

This study could extend the wave-current research in three important areas: (1) the relatively high numerical resolution could solve the problems of the stronger wave-current interaction in the nearshore region, (2) answer a more fundamental question of how waves should enter the dynamics with the influence of ambient currents in the high resolution numerical model, and (3) the selection of Great Lakes as a modeled region could simplify the modeling and analysis of the wave effects in order to accurately wipe out the effect of astronomical tides. In this regard, the first part of this study provides an answer. It shows the relevant interaction between waves and currents.

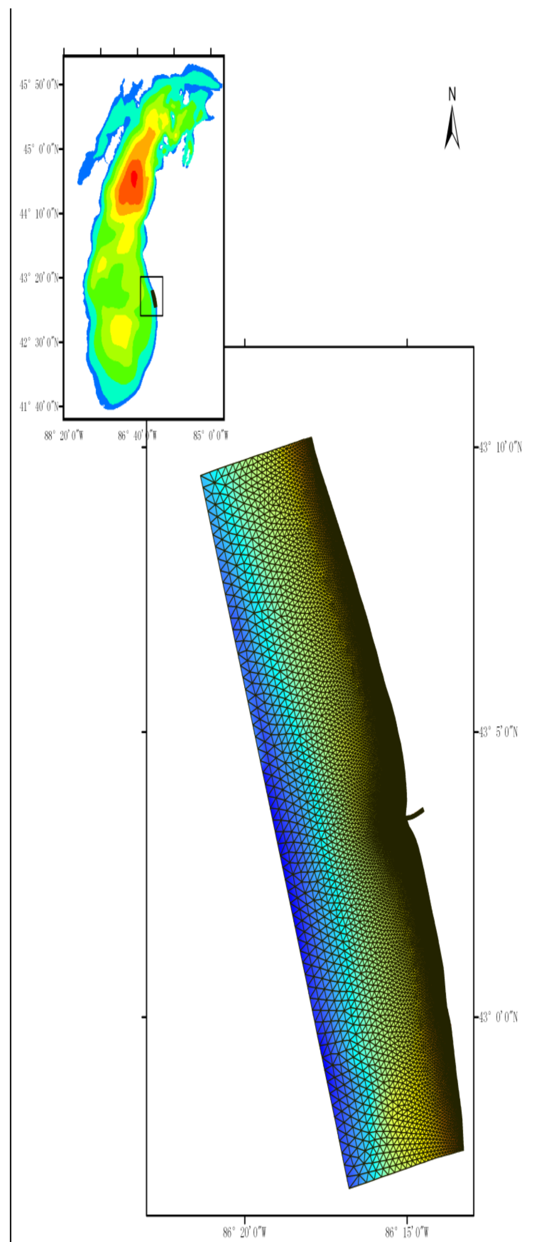


Figure 1. The location of the Grand Haven area.

NUMERICAL MODEL

FVCOM is a prognostic, unstructured-grid, finite-volume, free-surface, 3-D primitive equation coastal ocean circulation model developed by UMASSD-WHOI. It is a hydrodynamic modeling system, capable of simulating the hydrodynamic processes due to waves, rivers, winds, and ambient currents (Chen et al. 2006; Qi et al. 2009). By implementing finite-volume algorithms, SWAN was converted into an unstructured-grid based finite-volume model (hereafter referred to as FVCOM-SWAVE). FVCOM-SWAVE was coupled with FVCOM circulation models for the study and simulation of current-wave interactions. A detailed description about the finite-volume algorithms used in FVCOM-SWAVE was recently published by Qi et al. (2009).

MODEL SETTING

In order to resolve the alongshore-current feature of the relatively small coastal area and the river levee, high resolution-modeling domains (Figure 2) were employed with 25,000 elements in this study. This high resolution-modeling domain resolves more detailed geographic features in and around the jetty and shallow waters. The embedded nested grid uses the unstructured grid that reaches around 10 m at the coastline and 5 km at the coastal boundary.

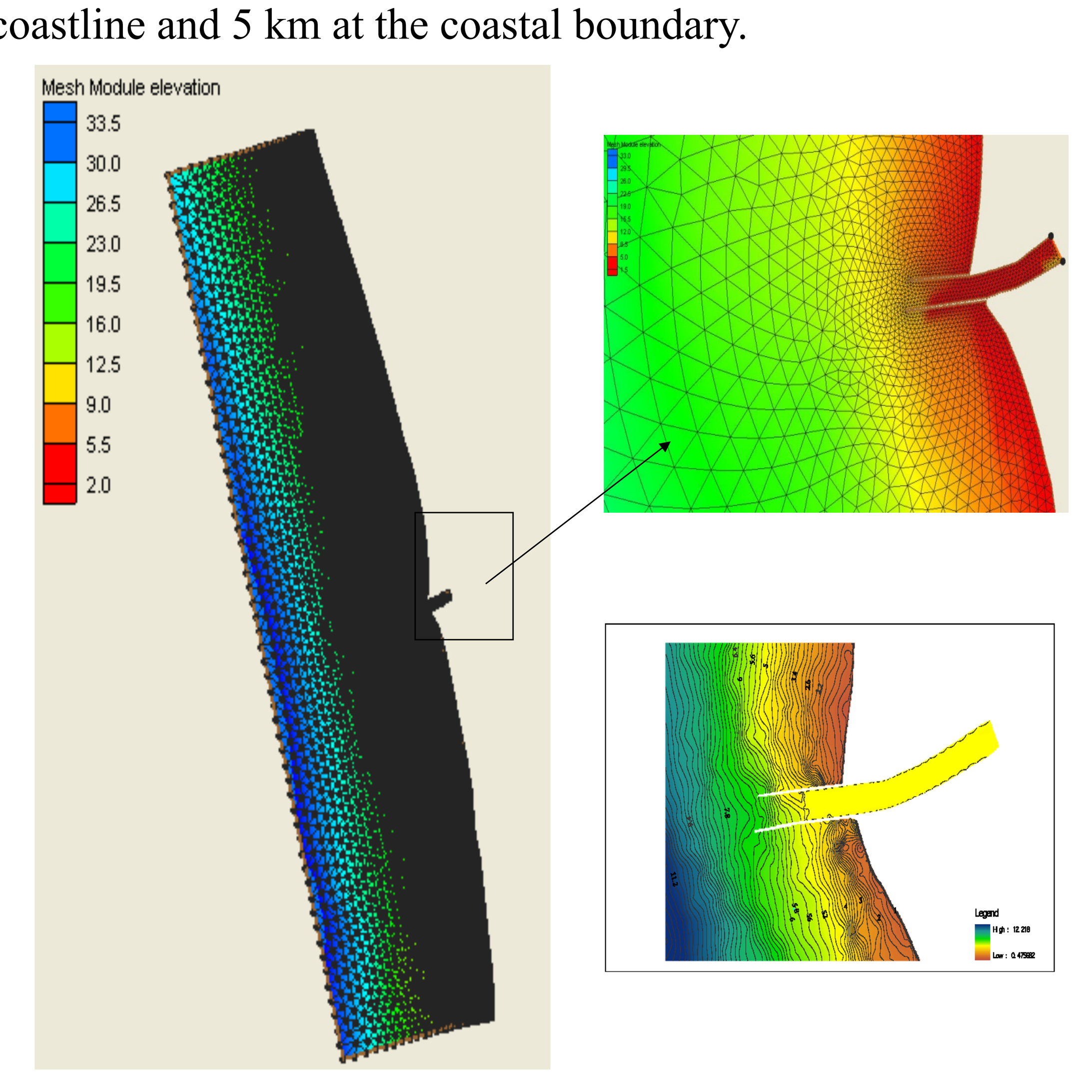
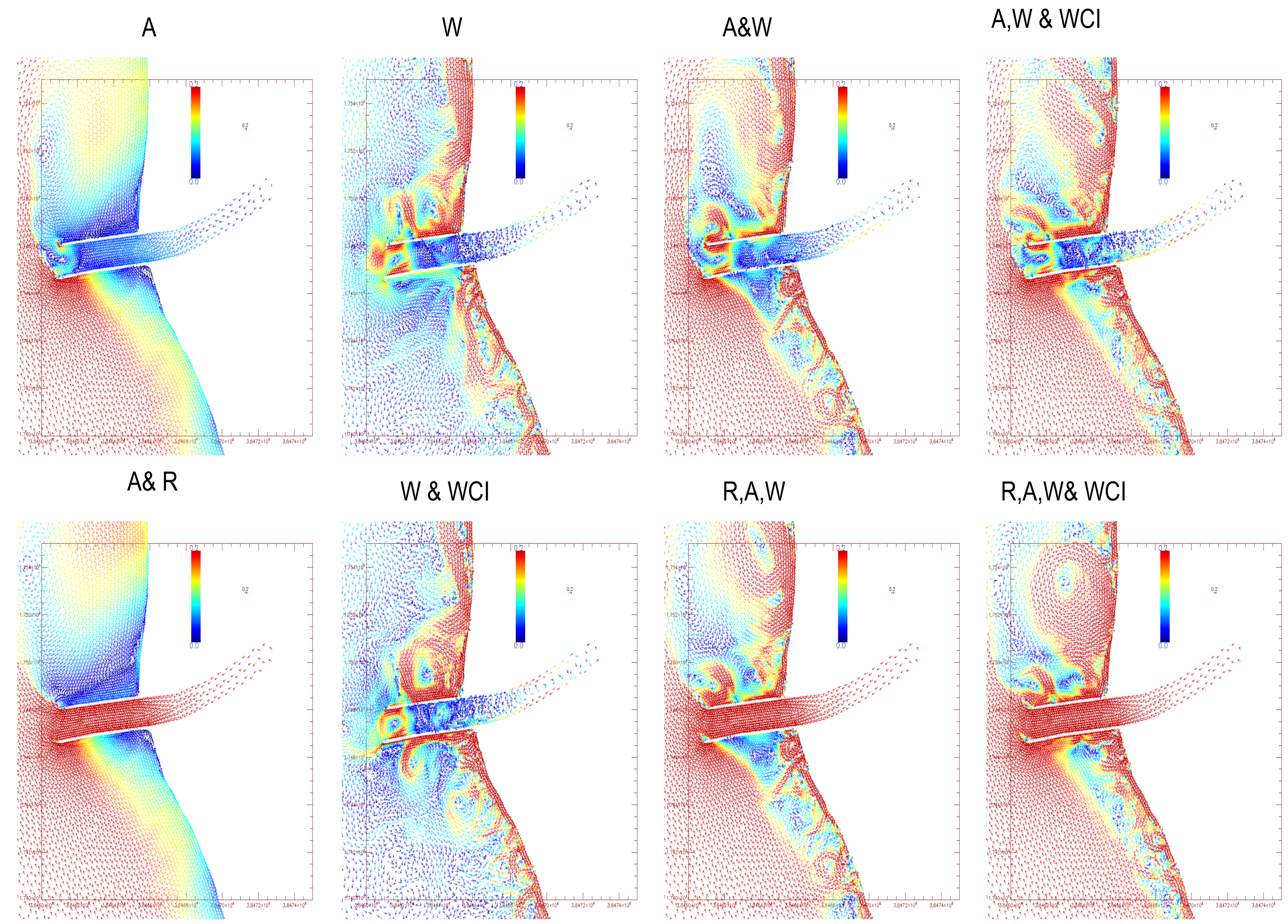


Figure 2. Model domain of Wave-Current Grand Haven Model.

MODEL RESULTS



R	River		WCI	Wave-Current Interaction
W	Wave		A	Ambient Flow

CONCLUSIONS

1. The beach area is influenced slightly by the freshwater inflow, although the freshwater inflow influences the circulation pattern at the river mouth.
2. Ambient flow has little influence on the nearshore circulation. There seems to be a boundary between the ambient flow dominated area and the area dominated by the effect of wave-induced circulation.
3. Circulation in the beach region was dominated by wave-induced nearshore circulation. There is a significant strong current region along the coast.
4. The current-wave interaction is more prominent near the jetty region.

REFERENCES

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2. Qi, J. C. Chen, R. C. Beardsley, W. Perrie and G. Cowles, 2009. An unstructured-grid finite-volume surface wave model (FVCOM-SWAVE): implementation, validations and applications. Ocean Modelling, 28, 153-166. doi:10.1016/j.ocemod. 2009.01.007.